EFFECTS OF FALLOW REPLACEMENT GREEN MANURING WITH ANNUAL LEGUMES ON SOIL NITROGEN AVAILABILITY

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ABSTRACT

Legume green manures are used in crop rotations to enhance soil nitrogen availability and to provide ground cover for soil conservation. The annual legumes Black Lentil, Chickling Vetch, Tangier Flatpea, and a Feedpea were grown with tall stubble snow trapping in rotation with spring wheat to determine their suitability for fallow replacement in wheat production systems in the Brown soil zone. The field experiment, conducted at Swift Current Research Station from 1984 to 1991, was designed to assess the different legume types and green manure management practices (inoculation, incorporation, and desiccation). The RCB included fallow-wheat and continuous wheat as controls. Only continuous wheat received nitrogen (N) fertilizer. Soil N availability was measured by analyzing five soil segments down to 120 cm depth for exchangeable ammonium and nitrate up to four times each year. The topsoil was also analyzed by an incubation/leaching technique to determine the potential N mineralization after three cycles of the rotation in 1990. Soil nitrate showed large treatment related variation. Nitrate values for legume green manuring were consistently higher after incorporation than after desiccation. In all treatments, topsoil nitrate was high in spring and lowest in July. In fall and spring following fallow and green manuring nitrate was high for the fallow-wheat and the legume-wheat rotations and low for continuous wheat. The initial potential rate of nitrogen mineralization reveals a lower nitrogen supplying power of the topsoil for fallow wheat than for legume/wheat and for fertilized continuous wheat.

INTRODUCTION

Campbell et al. 1990, conclude from review of crop rotation studies on the Canadian prairies that summer fallow is a legitimate option in the cropping systems of western Canada since it reduces economic risks where soil moisture stress is the primary yield limiting factor. This applies in particular to the Brown and Dark Brown soils. Still, there is also growing concern that agricultural production based on fallow systems is not sustainable. Scientific evidence has been provided to prove the detrimental effects of fallow on farming soils and to demonstrate the merits of fallow replacement (Biederbeck et al. 1984; Campbell and Souster 1982).

In the search for sustainable development in prairie farming a fundamental research trial was implemented at Swift Current research station during the past decade to study fallow replacement with legumes that were grown as green manure (Biederbeck and Slinkhard 1988). The objective of the experiment was to study the suitability of annual legumes for green manuring in the Brown soil zone and investigate the benefits of different green manure management practices. The Brown soil zone is characterized by small grain farming under a very dry and quite erratic precipitation regime. Those marginal site conditions have always been considered to be the major constraint for any fallow replacement and limited previous rotation studies predominantly to fertilization and crop management studies. Therefore, the annual legume green manure study has provided an unconventional set of data which will be presented to some extent in this paper.

Although the beneficial effects of legumes appear to be numerous and important to soil conservation, this paper will focus on the nitrogen cycle of annual legume wheat rotations. The nitrogen cycle can be grouped under two aspects: (I) The capacity aspect that is the amount of nitrogen stored and immobilized by legume based fixation in the organic component of agrosystems. (II) the intensity aspect that is the rate at which fixed nitrogen is mobilized and released from the organic pool. It is the first aspect that creates usually concern about further mining of the indigenous soil nitrogen resource by summer fallowing. But the replenishment of the lost soil organic nitrogen resource is not necessarily a direct concern to crop producers. It is the intensity aspect that has to be paid attention to in the first instance since summer fallowing does not only replenish soil moisture. It also refills the plant available nitrogen reserve and reduces nutritional stress. Thus, annual legumes wheat rotations have to be evaluated primarily with respect to soil nitrogen mobilization and it has to be demonstrated that annual legume green manure as supposed to summer fallow can sustain soil nitrogen availability for crop production. In this context Campbell et al. (submitted) provided promising data from a rotation study in the Brown soil zone that suggest progressively increasing soil nitrogen availability and reduced fertilizer demand due to fallow replacement by grain lentil in a wheat cropping system.

A critical intensity aspect for evaluation of legume-wheat rotation are volatile losses of nitrogen. Legume residues have relatively high nitrogen concentration and the nitrogen occurs to a larger extent in labile compounds when the residues are applied as green manure at an immature stage. In other words legumes fix gaseous nitrogen but agronomic green manure practices lead to the release of nitrous gases or ammonia (Aulakh et al. 1991; Janzen 1990) which are nowadays known as green house gases and of environmental concern.

MATERIAL AND METHODS

The study was set up on a Swinton loam in 1984 and lasted until 1991. It included six different six different rotations. Except for the first year four different legume-wheat rotations, continuous wheat and fallow-wheat were grown during the experiment. The entire study was replicated to grow both rotational phases each year. All rotations received phosphorous fertilizer. Only continuous wheat was fertilized with nitrogen. Usually, the annual legumes Black lentil (BL), Tangier Flatpea (TFP), Chickling vetch (CV) and a feedpea (FP) were seeded in the legume phase as green manure (GM). Inoculation (INOC), uninoculation (UNOC), incorporation (INC), desiccation (DES) and legume growth to seed maturity like grain legume (GL) without harvesting of the seed were practiced as green manure management.

A change in the experimental design and legume seed deficiencies occurred in the first two years of the experiment. Since 1986, the rotations and management practices were consistent. Details on site conditions, experimental design, agronomic practices and sampling procedures have been described elsewhere (Biederbeck and Slinkhard 1988).

The plant availability of soil nitrogen was determined by analyzing soil extracts from five depth segments by standard procedures (Winkleman 1990) for ammonium and nitrate nitrogen. After three rotational cycles soil was sampled at wheat stubble in late fall to determine the initial potential rate of nitrogen mineralization by an incubation-leaching method. The theory and the derivation of the rate constants was described elsewhere (Campbell et al. 1988).

Data analysis was based on a randomized complete block design with four replicates and with split plot arrangement of the treatments.

For mass balance calculations and data presentation the extractable soil nitrogen fraction was converted from ppm values to nitrogen pool values on a kilogram per hectare basis. The conversion accounted for soil bulk density and for its change with increasing soil depth based on measurements that were obtained by a proceeding experiment (Dyck et al. 1977) at the same location. The fine earth content of the soil which is included in a conversion equation proposed by Khanna and Ulrich (1984) has been neglected due to lack of data. The readily plant available soil nitrogen data as referred to as soil nitrogen in this paper represent nitrate nitrogen values.

To estimate the apparent fixation of atmospheric nitrogen two different mass balance approaches were applied as proposed by Biederbeck and Slinkhard (1986) and by Campbell et al. (submitted). The first approach is solely based on the difference of the nitrogen uptake by plants in plots inoculated with nitrogen fixing rhizobium bacteria and uptake in uninoculated plots. The Campbell approach accounts for plant uptake, changes in plant available soil pool, fertilization and nitrogen losses. it does not include atmospheric nitrogen deposition. When using the later approach in this paper nitrogen losses were assumed to be negligible.

RESULTS

The use of soil nitrogen to build up green manure biomass during the legume phase from spring seeding to July was strongly affected by weather conditions. The effects are shown for a dry and a wet year in figure 1. Effects of legume species were not significant. Soil nitrogen use of legumes was very low in the wet year of 1986 when rainfall above long term average provided soil moisture conditions that were favorable to soil microbial activity. Some negative nitrogen use values for this year indicate that nitrogen losses occurred either due to leaching below 120 cm soil depth which had not been sampled and/or due to denitrification under temporarily anaerobic conditions at high soil moisture levels (Auklakh et al. 1991).

High soil nitrogen use occurred in the legume phase of dry years like in 1988 when rainfall during growing season was slightly below long term average but evapotranspiration extraordinarily high (Cutforth pers. comm.). The interaction of soil nitrogen use and weather conditions matches the understanding that soil microbiological activity is a function of the soil moisture conditions. Favorable soil moisture conditions increase the rate at which soil organic nitrogen is mineralized. Thus, a high turnover from the soil organic pool to the plant available pool makes good for the loss due to plant uptake in a wet year while in a dry year the plant nitrogen demand has to be buffered to a much larger extent by depletion of the readily plant available soil reserve. The nitrogen use results imply that timing of green manure according to weather conditions is not only crucial to provide sufficient soil moisture but also enough soil nitrogen for the subsequent wheat production phase.

The comparison soil nitrogen use that is provided by table 1 for inoculated and uninoculated legumes does not show much consistency. During the first three years both treatments reveal usually similar results. This indicates that the much higher green manure biomass build-up of inoculated treatments could have only been realized by saturating the additional nitrogen demand through fixation of atmospheric nitrogen. The pronounced increase in soil nitrogen use of inoculated legumes in 1988 can be explained by a closer look at the dry matter production values of table 2. The data clearly show a dramatic increase in weed infestation of the legume phase. For example, Tangier flatpea is so strongly weed infested since 1988 that the legume component is reduced to 25% of the total above ground biomass. This suggests that the nitrogen contribution due to fixation is reduced while the demand for soil nitrogen is increased due to predominant weed growth. The negative value for soil nitrogen use of uninoculated legumes in 1988 can not be explained.

The annual nitrogen contribution of nitrogen fixation to the soil organic pool are shown in table 3 for a six years period. On the basis of plant uptake, the amount of fixed nitrogen ranges from 9 kg/ha for Tangier flatpea in the dry year of 1984 to 68 kg/ha for Chickling vetch in the wet year of 1986. The fixation estimate on this basis must be considered to be highly over estimated for the year 1988 because of the uneven weed infestation of uninoculated and inoculated legumes. But also in the following year the beneficial effect of nitrogen fixation must be questioned if it goes together with high nitrogen immobilization in weed organic matter that leads to leads to a depletion of the soil nitrogen reserve. A much better figure for the net nitrogen effect of weed infested legumes to the plant available nitrogen pool is provided by the fixation estimate approach that accounts for changes in the plant available soil nitrogen reserve. The values for 1988 and 1989 (see Table 3) demonstrate clearly that weed infested legumes can have a substantial negative net effect on the soil nitrogen reserve. However, the considerations on nitrogen fixation show again the importance of green manure management practices over selection of the right legume species since the inclusion of a legume phase for green manure in wheat cropping systems requires careful weed control as part of the agronomic management.

At spring seeding of the wheat phase the most pronounced differences in the soil nitrogen availability occur among different green manure management practices (see Figure 2). The higher availability under incorporation than under desiccation confirms findings that were obtained for the Dark Brown soil zone (Brandt 1990). The results suggest that residue placement is an important factor in green manure management. Most striking is the effect of inoculation and its underlines again the importance of this practice. The higher availability under green manured treatments than under legumes that were grown to seed maturity confirms the understanding of a more unterminated nutrient uptake pattern in legume systems as supposed to wheat and it also confirms the lower decomposability of seed and mature plant material.

Among green manures, continuous wheat and fallow soil nitrogen availability differed in the top 60 cm of the soil profile (see Table 4). Over the years, values are consistently highest for fallow and usually lowest for continuous wheat. From those results at least two conclusions can be drawn but they can not be differentiated quantitively:

a) The rate at which legume residues mineralize was not high enough to replenish the plant available soil nitrogen reserve with an amount of nitrogen that was equal to what had been provided due to mineralization of indigenous soil organic matter under fallow.

b) A significant amount of nitrogen from legume residues disappeared from the system due to volatile losses.

Some further explanation for differentiation may be derived from the results of the soil testing for the initial potential rate of nitrogen mineralization which are presented in Figure 3. The results show that green manuring and fertilization in the case of continuous wheat have a potential to mineralize soil organic nitrogen at a higher rate than the summer fallowed treatment. Since those measurements were taken on soil that was sampled at the end of the wheat phase after three rotational cycles, it can be concluded that the mineralization of green manure is delayed and green manuring gradually improves the nitrogen supplying power of the soil organic matter. However, the results for plant available nitrogen can not be fully evaluated since experimental evidence has been provided for volatile losses from legume residues. This should be subject to further research to ensure environmentally friendly green manure management practices.

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Table 1. NO3-N use in legume phase from seeding to green manure incorporation from 0 - 120cm; [kg/ha]

DATE	INOC	UNOC	LSD (p = 0.05)
1985	35	46	61
1986	7	21	78
1987	12	24	45
1988	61	-4	36
1989	65	18	68

Table 2. Above ground drymatter in legume phase at green manure incorporation; [g/m^2]

MANAGEMENT		INOC				UNOC				
GREEN MANURE		BL	TFP	CV	FP	BL	TFP	CV	FP	LSD at p=0.05 (MGMT x GM)
LEGUMES	1984	131	105	142	143	65	62	53	72	84
	1985	150	158	213	254	54	77	87	121	26
	1986	169	145	276	318	87	82	119	164	23
	1987	193	185	250	314	69	55	86	97	36
	1988	86	52	133	137	72	72	99	101	51
	1989	147	134	184	360	135	50	101	210	72
	1990	159	113	91	194	-	-	-	-	-
WEEDS	1984	0	0	0	0	0	0	0	0	0
	1985	22	19	8	4	5	1	1	0	14
	1986	24	27	14	5	11	12	9	3	27
	1987	2	12	2	1	22	60	32	49	16
	1988	135	142	80	71	15	30	9	21	77
	1989	234	243	224	102	184	226	241	140	81
	1990	98	123	130	93	-	-	-	-	-
TOTAL	1984	131	105	142	143	65	62	53	72	84
	1985	173	177	222	257	59	78	88	121	27
	1986	193	172	290	322	98	94	128	167	25
	1987	195	197	252	315	91	115	119	146	41
	1988	220	194	213	209	87	101	108	122	51
	1989	381	377	408	462	319	275	342	351	94
	1990	257	236	221	288	-	-	-	-	-

Table 3. Annual nitrogen fixation estimate for different type of annual legume [kg/ha]

BASIS	PLANT UPTAKE				PLANT UPTAKE AND SOIL N CHANGE			
	GREEN MANURE							
DATE	BL	TFP	CV	FP	BL	TFP	CV	FP
1984	14	9	21	11	44	-35	-2	32
1985	29	29	39	46	63	53	68	4
1986	37	33	68	61	36	36	73	110
1987	34	25	39	41	19	56	49	62
1988	43	35	33	28	-30	-41	10	-59
1989	45	60	47	38	-6	39	-19	-10

Table 4

NO3-N AT SPRING SEEDING IN WHEAT PHASE [KG/HA] UNDER DIFFERENT TYPE OF GREEN MANURE

DATE	GREEN MANURE						
	BL	TFP	CV	FP	CW	F-W	LSD ($p = 0.05$)
1986	61.6	57.0	54.6	55.1	54.9	84.3	20.1
1987	57.0	59.4	61.8	51.9	35.8	75.7	18.2
1988	73.4	82.8	75.7	70.0	54.2	98.9	24.2
1990	82.6	65.6	62.0	61.3	36.4	104.4	25.8

Figure 1. Soil nitrogen use of inoculated legumes from seeding to green manure incorporation from depth 0 - 120cm; LSD (green manure x year) = 27 kg/ha at p = 0.05.

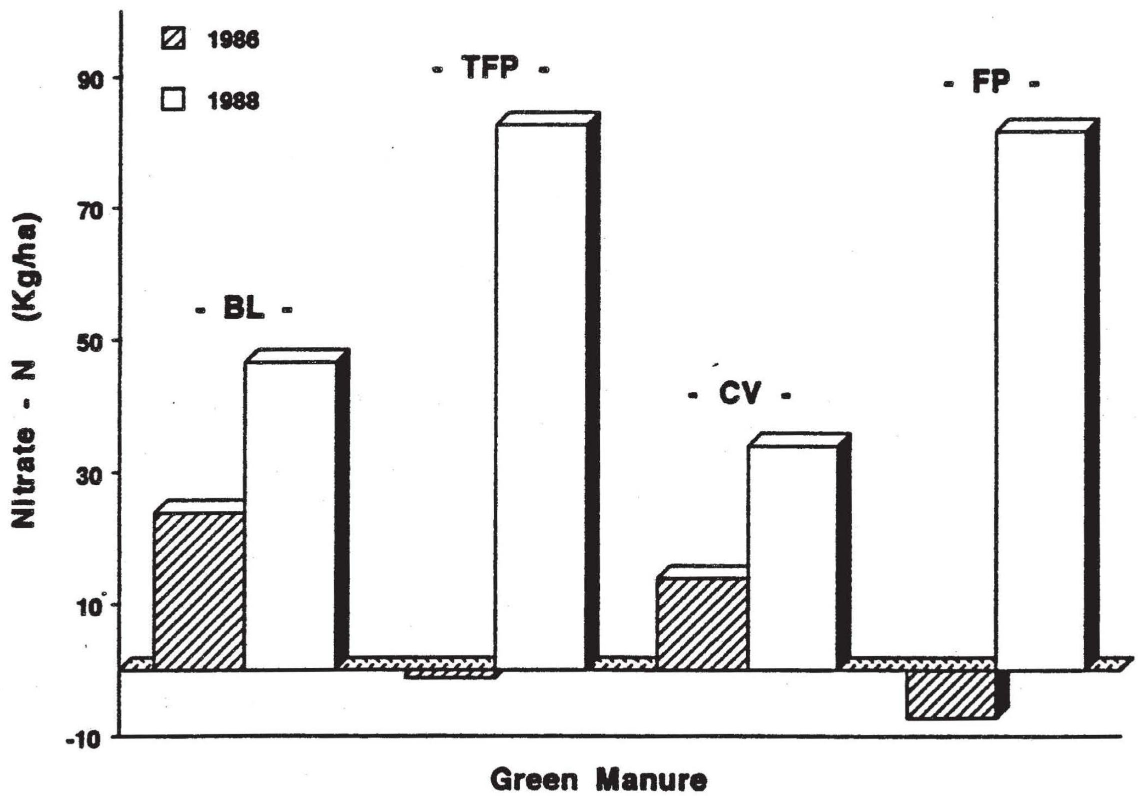

Figure 2. Soil nitrogen availability in spring of wheat phase in depth 0 - 60cm in 1987; all three comparisons are signaficantly different at p = 0.05.

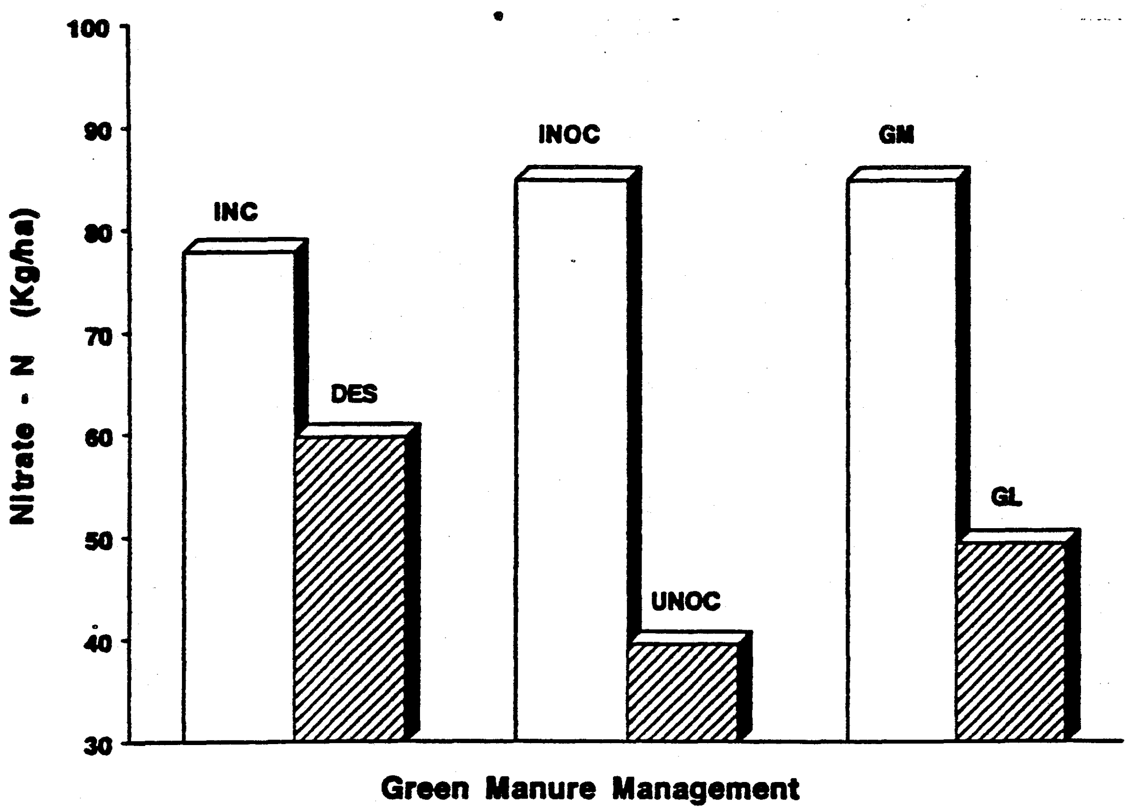

Figure 3. Intial potential rate of nitrogen mineralization (Nok) of soil under wheat stubble in fall after three rotations; LSD = 6.33 lbs/acre/week